20

CONSTRUCTION OF A 14 MEV NEUTRON GENERATOR UTILIZING $T^3(d, n) He^4$ REACTION AND MEASUREMENT OF FAST NEUTRON FLUX*

BIMALENDU MITRA

BOSE INSTITUTE, CALCUTTA-9

(*Received for publication, March* 14, 1959)

ABSTRACT. Construction of a low voltage accelerating machine for accelerating deuterons which is utilized as a source of production of 14 Mev neutrons, by T^3 (d,n) He^4 reaction, has been described. Neutron counting has been done by counting recoil protons in a suitable scintillation counter. Neutron yield has also been measured indirectly from saturated activity of an irradiated thin silver foil. Increase in relative flux with increasing deuteron energy from 30 Kev to .1 Mev has been obtained.

1. INTRODUCTION

Banerjee (1955) reported previously the construction of a neutron generator in the Bose Institute The machine was capable of focussing 2 microamperes of deuteron beam current accelerated to 52 kilovolts, on a Zr—T target placed at a distance of 34". The yield was also determined which was about 1×10^7 neutrons per second in the experimental condition. It was then proposed that a larger machine capable of a much greater and continuous yield of neutrons be built up in the laboratory in addition to the existing one. The present author has successfully built up such an apparatus in the Institute. The instrument is (i) more compact, almost portable, and (ii) has high efficiency with very large neutron yield.

2 CONSTRUCTION

The apparatus, like the previous one, is a low voltage deuteron accelerator which is utilized to produce 14 Mev neutrons by the following reaction :

$$H^2 + H^3 = He^4 + n + 17.6 \text{ Mev}$$

Deuterium gas is obtained by electrolysis of heavy water and stored in an one-litre flask at nearly normal pressure. This gas is led into an ion-source made of pyrex glass through a fine needle valve. The ion-source is similar to that which has been described by Moak, Reese and Good (1951), but differing in a few details.

*Partly reported in Low Energy Nuclear Physics Symposium 1959, organised by the D.A.E

It is also of large volume, nearly 350 c.c., to minimize the space charge effect and the exposed metallic parts have been kept minimum. The electrodes are carefully concealed within projecting pyrex glass jackets. Figure 1. shows the schematic drawing of the ion-source.

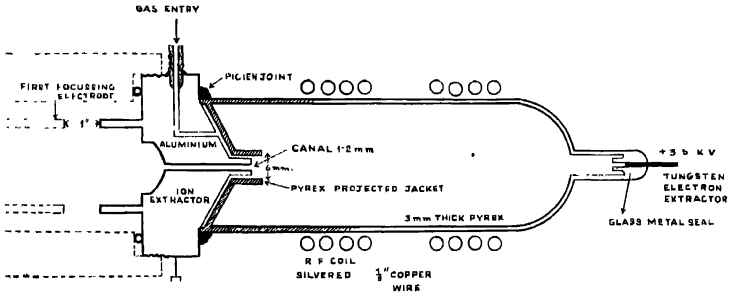

Fig. 1. Ion source.

A radio-frequency discharge is maintained in the ion-source by means of an oscillator of frequency 20-22 megacycles per second and capable of delivering nearly 200 watts of power (figure 2). Loss in the output of the oscillator is minimized by use of a parallel transmission line upto resonating coil round the discharge tube and matching the impedance by trials with dimension of the exciting coil. A second resonance circuit's coil is kept near the first coil, placed axially with the discharge tube and energy transferred to it by link coupling. Diameter of the coils is 2.3" and it is $\frac{1}{8}$" thick silvered copper wire, having 6 turns. The variable condenser has vanes separated by 4 mms and immersed in oil.

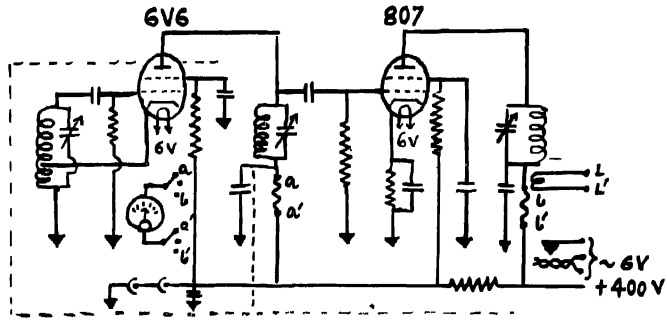

Fig. 2(a) Master oscillator and driver unit of R. F. oscillator, 15-30 Mc/s.

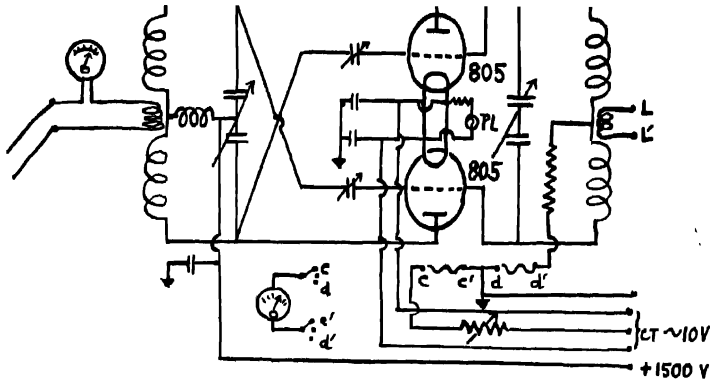

Fig. 2(b) Amplifier unit.

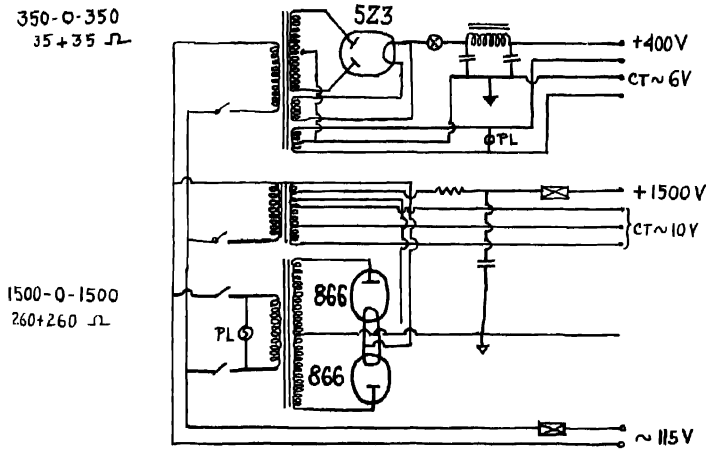

Fig 2(c) Power supply unit.

Under the experimental condition this frequency band of 20-22 megacycles has been seen to be most effective in producing maximum ion current. A magnetic analysis of ions produced in such an ion-source has been previously done by Banerjee (1953) under nearly the same experimental condition, which showed that more than 60% of the ions produced were atomic ions. The ions are drawn out of the discharge tube through an orifice in the aluminium probe in the discharge tube.

Figure 3 is the photographic record of the deuterium discharge, close to the probe canal. The discharge when viewed by a direct visions pectrograph shows three clear spectral lines, α, β, γ, corresponding to Balmer lines of hydrogen. The ions, drawn out of the discharge tube is focussed electrostatically by means of two 1/16″ thick cylindrical aluminium electrodes. The lengths of the focussing and next accelerating electrodes are 18″ and 4″ respectively. The inner diameter is 2.8″, but the first focussing electrode has a six-inch part of it of different diameter being 1.8″. Information regarding the design has been greatly obtained from the pioneering works of Tuve *et al* (1935) who conducted detailed experiments with various kinds of such electrostatic lenses for focussing positive ions.

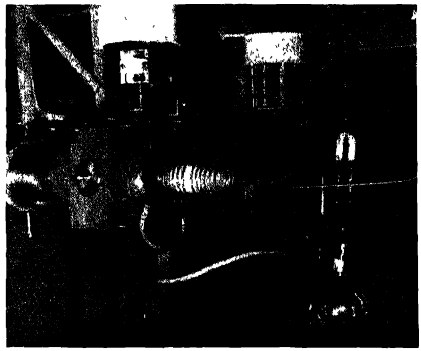

Fig. 3 Photograph of ion-source showing deuteron discharge close to probe-canal

The electrodes are held within 0.25″ thick Index glass cylinders, specially made for this work by Messrs Sigcol Ltd., Calcutta, having inner diameters 3.75″ and lengths 6″, 9″ and 2″ respectively. Each cylinder is flanged at either end having ground flat surfaces. The whole assembly forms a cylinder, whose different parts are made vaccum tight by greased O'rings and suitable clamps. The general arrangement is shown in the figure 4.

The target is fitted on a circular brass plate which is clamped at the end of the accelerating cylinder. The accelerator including the ion-source has an overall length of 24″ only and rests in a horizontal position on two insulating perspex stands. The accelarator tube and the ion-source with the aluminium probe extractor are attached to the two shorter limbs of a T-shaped mild steel tube of inner diameter 4″ – the longer end of the tube is connected to the vacuum system.

This T-tube has been bored from a solid block of steel to avoid any possible vacuum leakage.

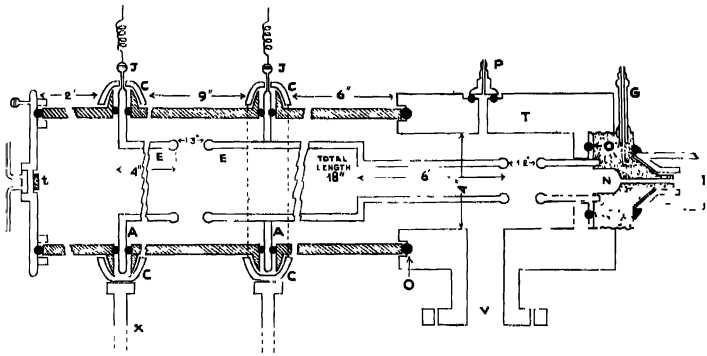

Fig. 4 I -Ion source, G—deuterium gas entry, K-probe-canal, P- -Pirani gauge head, V—vacuum connection, T- T-shaped mild steel tube, E -aluminium electrodes for electrostatic focussing, A --aluminium rings for holding the electrodes in position, C—clamps, O—neoprine O'rings, t--target, J —high voltage leads, x -Perspex stands

The pumping system consists of Leybold's OT 100 and D 10 oil diffusion and backing pumps respectively, having pumping speed of 100-120 litres per sec. and reaching an ultimate vacuum of 10^{-6} mm of Hg There is arrangement for inserting a Pirani gauge head close to the probe canal.

For typical operation, the ion-source probe attached to the T-tube is kept at zero potential while the tungsten electron-extractor at the other end of the ion-source kept at + 3.5Kv, the first focussing electrode and the second accelerating electrode are given successively increasing negative potentials. The target is kept 500 volts negative with respect to the preceding electrode.

The targets have been procured from AERE, Harwell, and consist of Tritium gas adsorbed in Titanium metal, deposited on a copper disc. The target contains about 1.4 mg. of titanium in which .61 c.c. of 97% pure tritium gas is absorbed.

The high voltage apparatus consists of a rectifier-voltage doubler circuit capable of giving 125 Kv at 500 milliamps from 50 cycles A.C. supply (figure 5) For greater voltages, the existing R. F. Cockroft Walton type generator, capable of giving 400 μ amps of current at 240 Kv D.C. potential can be used. Output 10 Kv from the r.f. oscillator, at 100 kc/s is multiplied 24 times.

In a particular experimental condition, a total beam current of more than 500 μ amps has been obtained, focussed under 75 Kv., on the target within a

circular spot of nearly 1 cm in diameter. But for the experimental purposes current is now kept limited to only a few μ amps, because of two considerations

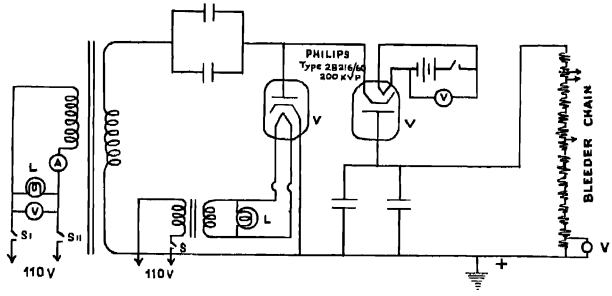

Fig. 5. 125 Kilovolts high tension unit

(1) Target requiring more efficient cooling arrangement (2) Neutron shielding of the apparatus requiring more eloborate arrangement Cooling is now proposed to be done by refrigerated CCl_4 liquid circularing in a closed system through polythene tubes.

At present the apparatus is kept in a second storeyed room of the laboratory and the room is air-conditioned where humidity control is possible. As the neutron shielding is difficult in an upper storeyed room, the apparatus has been proposed to be shifted to an underground room, under construction for its own.

3. MEASUREMENT OF NEUTRON-FLUX:

The nutrons have been detected by counting recoil protons with the help of a photomultiplier-scintillation detector employing ZnS in perspex as phosphor. The tube used is EMI type 6260. The measurement of neutron flux has been done in the following way

Fast neutron flux turns the silver nuclei, present in silver metal in normal isotopic forms Ag^{107} and Ag^{109} in the ratio 51.35% : 48.65%, to radioactive silver, Ag^{106} and Ag^{108} by mainly $(n, 2n)$ reaction. The decay scheme of them is the following :

$$Ag^{107}(n, 2n)Ag^{106} \xrightarrow[24\ min]{\beta^+} Pd^{106}$$

$$Ag^{109}(n, 2n)Ag^{108} \xrightarrow[2.3\ min]{\beta^-} Cd^{108}$$

The cross section of (n-2n) reaction in both the cases is fairly well known. Hence by irradiating a very thin silver foil long enough in the fast neutron flux to get the

2.3 min. saturated activity, and counting product β-particles we can know the equivalent activity. Then neutron flux is given by

$$(nv) = \text{no. of neutrons/sec. cm}^2 = \frac{A}{N\sigma} \quad \ldots \text{(i)}$$

A = equivalent activity

N = no of nucleii/cm^2 in sample foil

$\sigma = (n, 2n)$ reaction cross section.

The actual count in the β-counter is related to total disintegration rate by a formula :

$$\frac{c}{m} = \frac{d}{m} \cdot E \cdot f_t \cdot f_B \cdot f_w \cdot f_s \quad \ldots \quad \ldots \text{(ii)}$$

where $\frac{d}{m}$ = disintegration rate

$\frac{c}{m}$ = actual count rate

E = corrected efficiency of the counter

f_t = counter dead time correction factor

f_B = backscattering correction factor

f_w = factor for correction of absorption in window, air and counter wall etc.

f_s = self-absorption factor

In the investigation a very thin silver foil is attached to the atmospheric side of the target It is circular, having diameter exactly 1", i.e. being equal to the tritium absorbed layer of the target. It is irradiated by fast neutron flux for 10 mins. During the irradiation, pressure inside the ion source is adjusted very cautiously by the needle valve so that the ion-current indicated by the microammeter in series with the target connection, remains strictly constant. The oscillator output remains constant, as shown by a r.f. ammeter in series with the coil.

The total accelerating voltage used is 62 kilovolts, total beam current kept fixed at 50 μ amps. The focus spot can easily be marked on the target by its deep bluish colouration and is less than one cm in diameter. The ion-source probe voltage is 3.5 Kv. The discharge current is 2.5 mA. The potential in the first focussing electrode is 37.5 Kv.

Waiting for 1½ minutes after irradiation, the thin foil, having a thin aluminium backing, is held under an end window β-counter (having 3mg/cm^2 window thick-

ness) in a fixed geometry. The decay curve is plotted as number of counts per minute (every half minute interval) against time and from this decay curve, initial activity is extrapolated, assuming that in 10 minutes, saturation is reached for 2.3 minute product.

In the formula (ii), E is the product of geometrical factor $\frac{\omega}{4\pi}$ and probability ϵ of counting a β particle which enters the counter, neglecting multiple pulses. The relative value of E has been determined by the help of a P^{32} standard source of known strength prepared from sodium phosphate of 2mc/ml strength. P^{32} beta particles have nearly the same energy as Ag^{108} betas. The other corrections are made after usual procedures. The correction f_B is taken from the backscattering curves obtained by Zumwalt (published in the U.S. AECU—567), for P^{32} radiation, with Al backing, f_s have been neglected because the foil is a very thin one. The value of σ has been obtained from Los Alamos results given in USAEC, —BNL325. Calculation from (i) shows in this experiment, 50 μa of total beam accelerated upto 62 Kev, yield 1.4×10^9 neutrons/sec/cm^2 passing through the foil attached on the atmospheric side of the target.

4. VARIATION OF NEUTRON YIELD WITH INCREASE OF DEUTERON ENERGY

Bretscher and French (1948) studied the cross section of (d, t) reaction for projectile energy upto 125 Kev, and their works showed the presence of a resonance at nearly 100 Kev

Conner *et al* (1952) studied the (T, d) reaction in details, employing tritium adsorbed targets, and varying the deuteron energy from 10 Kev to 1732 Kev. They obtained the maximum value of cross section at 109 Kev, σ_t being equal to $5.1\pm.1$ barns. From their curve it has been determined that increase of (T, d) reaction cross section, i.e. increase of product neutron yield is nearly 5 times at 100 Kev than its value at 51 Kev.

In the present investigation, the scintillation counter reading in a fixed geometry from the source has been calibrated to read neutron flux directly. Keeping the beam current constant and varying the projectile energy from 30 Kev to 100 Kev (the focus-spot on the target is seen to remain on the target area inspite of a little variation in the dimension of focal spot), counts per minute in the scintillation-detector, which counts recoil protons, is plotted against deuteron energy and thus variation in neutron yield with increase of deuteron energy has been obtained (figure 6).

The curve fits with the curve of Conner *et al* (1952) in voltage region lower than 100 Kev.

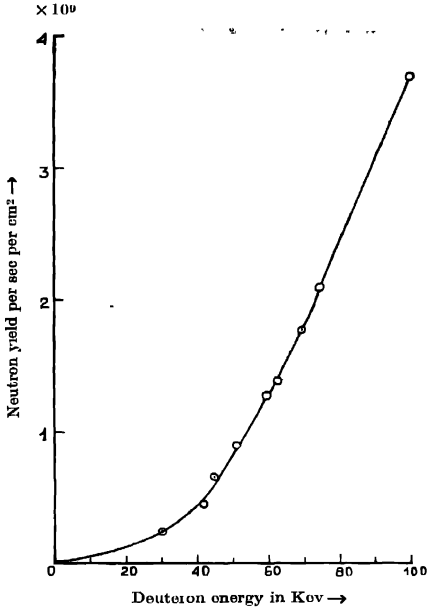

Fig 6. Curve showing neutron yield with increase of deuteron energy.

ACKNOWLEDGMENT

The author is grateful to Prof. D. M. Bose, Director of the Bose Institute for his keen interest in the work.

REFERENCES

Banerjee, A., 1953, *Ind. Jour. Phys.*, **57**,
Banerjee, A., 1955, *Science and Culture*, 454.
Brotzcher, E. and French, A. P., 1948, *Phys. Rev.*, **75**, 1154.
Conner, J. P., Bonner, T. W., and Smith, J. R., 1952, *Phys. Rev.*, **88** 468.
Moak, C. D., Reese, H. and Good, W. M., 1951, *Nucleonics*, **9**, 3.
Tuve, M. A., Dahl, O. and Hafstad, L. R., 1935, *Phys. Rev.*, **48**, 241.